反刍思维的脑功能网络机制

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摘要 反刍思维是指个体在经历了消极生活事件后不由自主地反复思考该事件的产生原因、经过和结果，表现出负性自我参照加工、消极情绪性以及持续性的特点。采用脑功能网络分析方法，研究者发现反刍思维的上述三个特点分别与默认网络内部的异常活动模式、突显网络功能连接的改变、以及注意相关网络之间的异常耦合模式有关。未来研究应进一步明确反刍思维与相关脑网络活动之间的因果关系，探究反刍思维脑功能网络的结构基础，同时也应关注反刍思维及其脑网络的老龄化特征，并致力于探索有效干预反刍思维的神经调控技术。

关键词 反刍思维，脑网络，默认网络，功能连接

1 引言

反刍思维(rumination)是指个体在经历了消极生活事件(如考试失利、感情受挫、工作不顺)之后，重复地思考该事件的产生原因、经过和结果而不能自已(Nolen-Hoeksema, 1991; Nolen-Hoeksema et al., 2008)。个体在反刍思维状态下通常会表现出以下认知和情感特点(Morrow & Nolen-Hoeksema, 1990)。首先，反刍思维使个体倾向于将消极信息与自我概念联系起来，进行负面的自我参照加工(Santa et al., 2012; 杨营凯, 刘衍玲, 2016)。其次，负性自我参照加工会使个体过度关注消极信息，导致消极情绪的产生并造成信息加工偏差，不利于问题解决(Constantin et al., 2017; Nolen-Hoeksema, 2000; Kertz et al., 2019)。第三，反刍思维具有持续性。一旦陷入反刍思维的状态，个体将长时间思考同一事件(Joorman & D'Avanzato, 2010)。简言之，反刍思维的负性自我参照加工、消极情绪性以及持续性损害了个体的问题解决和情绪管理能力，是一种非适应性的认知风格(Ando et al., 2020; Nolen-Hoeksema, 2000)。研究表明，反刍思维与抑郁症、焦虑症、双相情感障碍、创伤后应激障碍等多种精神疾病关系密切(Constantin et al., 2017; Dodd et al., 2019; Kraus et al., 2020; Kertz et al., 2019; Mihailova & Jobson, 2020; Smith et al., 2018; Topper et al., 2017)。鉴于反刍思维对心理健康所造成的显著影响，本文旨在梳理以往关于非适应性反刍思维脑神经机制的研究成果，以期理解反刍思维的脑功能网络基础，为干预反刍思维提供理论支持。

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近年来，大量研究采用功能磁共振成像(functional magnetic resonance imaging, fMRI)技术探讨反刍思维的大尺度脑网络(large-scale brain networks)机制。脑网络分析可以揭示认知过程所涉及的重要脑区以及这些脑区之间的相关性(徐龙洲, 2021)，近年来被广泛运用于认知神经科学研究(Delaveau et al., 2017; Kuhn et al., 2012; Menon, 2011; Sanchez et al., 2016; Sporns, 2014; Sin et al., 2018)。以往研究所揭示的大尺度脑网络主要有默认网络、突显网络、额顶网络、注意网络(Menon, 2011; Petersen & Sporns, 2015; Yeo et al., 2011)。研究表明，反刍思维状态下的负性自我参照加工与主要参与内部指向心理活动的默认网络有关(Berman et al., 2011; Chen et al., 2020; Rosenbaum et al., 2017; Zhou et al., 2020)；反刍思维的消极情绪性与突显网络的改变有关；其持续性则与注意网络之间的连接异常有关(Hamilton et al., 2011; Kaiser, Andrews-Hanna, Wager, et al., 2015; Li et al., 2018; Lydon-Staley et al., 2019; Price et al., 2017)。接下来，本文将分别就反刍思维的负性自我参照加工、消极情绪性、持续性的脑网络机制展开详细论述，并在此基础上展望未来研究方向。

2 反刍思维中的负性自我参照加工

个体在反刍思维状态下倾向于将负面信息与自我联系起来，并对之进行过度解读(Santa et al., 2012; Martin & Tesser, 1989)。具体而言，当发生了消极的事件，相较于客观地分析“这件事因何而发生”，高反刍思维者更多地表现出“我为什么表现得如此糟糕”、“为什么这种事情会发生在我身上”这种自省式的思维方式(Watkins et al., 2008)。研究表明，反刍思维的自我参照加工与默认网络活动模式的改变有关。

默认网络(default mode network)在要求投入注意力以处理外部信息的任务中活跃度降低，而在个体处于静息状态或进行与自我相关的抽象思维、情景记忆、未来想象等内部指向的心理活动时活跃度增加(李雨, 舒华, 2014; Buckner et al., 2008; Smallwood et al., 2021)。默认网络的改变在形成反刍思维的过程中具有关键的作用(Andrews-Hanna et al., 2014; Hamilton et al., 2015; Kaiser, Andrews-Hanna, Wager et al., 2015; Zhou et al., 2020)。研究发现默认网络由三个分工明确的子系统组成，分别是：①核心子系统，包含前部内侧前额叶(anterior medial prefrontal cortex)和后扣带回(posterior cingulate cortex)，参与自我参照加工并促进其他两个子系统之间的相互作用；②背内侧前额叶子系统(dorsal medial prefrontal cortex)，包含背内侧前额叶、颞顶联合、外侧颞叶和颞极(temporal pole)，在心理理论和元认知加工中起着重要作用(Andrews-Hanna, 2012; Andrews-Hanna et al., 2014)；③内侧颞叶子系统(medial temporal lobe)，由腹内侧前额叶(ventral medial prefrontal cortex)、后顶下小叶、压后皮层(retrosplenial cortex)、海马旁皮层(parahippocampal cortex)和海马体组成，其参与自传体记忆加工并基于此形成个体关于未来的情境性预期 (Andrews-Hanna et al., 2010; Spreng et al., 2009)。在反刍状态下，这三个子系统的活跃度与功能连接都发生了相应的改变(Andrews-Hanna et al., 2010; Tozzi et al., 2021)。

首先，反刍思维状态下三个子系统的活跃程度不同。多项研究通过让受试者判断特质

属性词、回想自己的消极事件以及思考他人对自己的评价等方法诱发被试的反刍思维，而后运用 fMRI 技术扫描受试者的大脑。结果表明，相较于分心状态，反刍状态下负责自我参照加工的核心子系统和负责心理理论加工的背内侧前额叶子系统活动度增加；然而，促成目标导向行为的内侧颞叶子系统的大部分区域在反刍状态下并不活跃(Apazoglou et al., 2019; Burkhouse et al., 2017; Cooney et al., 2010; Steinfurth et al., 2017; Vecchio et al., 2017; Zhou et al., 2020)。反刍状态下默认网络核心子系统的过度活跃提示，当外界刺激诱发个体产生反刍思维时，个体过多地对自我相关的信息进行加工。背内侧前额叶子系统则反映了个体由外界刺激而诱发的心理状态。即面对消极生活事件，反刍思维会使个体产生对自我的过度反思和否定，并将之投射为他人对自己的看法(如个体在比赛失利后陷入反刍状态，认为自己很糟糕，且认为他人也会觉得自己很糟糕)；而内侧颞叶子系统则基于自传体记忆形成关于个体未来的设想，所以反刍状态下内侧颞叶系统的活跃度不足可以理解为，个体难以提取自己经历过的积极事件，并认为自己很可能在预期目标中失败(如，经历过一次比赛失利后便认为自己在今后的比赛中都不会取得好成绩)。

其次，在反刍思维状态下，默认网络三个子系统之间的功能连接也发生了改变。Chen 等人(2020)用持续性精神状态范式(continuous mental state paradigm)考察受试者反刍状态的默认网络，并使用 3 台不同的磁共振扫描仪得到了高度一致的结果。与分心状态(想象与自己无关的事情)相比，反刍状态(重复思考消极事件及其可能产生的结果)下默认网络三个子系统之间的功能连接出现异常(Chen et al., 2020)。具体而言，在反刍状态下，核心子系统与背内侧前额叶子系统之间的功能连接减弱，而核心子系统与内侧颞叶子系统之间的功能连接增强(Bartova et al., 2015; Christoff et al., 2016; Chen et al., 2020; Provenzano et al., 2021; Zhu et al., 2017)。核心子系统负责统合其他子系统而背内侧前额叶子系统则负责元认知加工，两者之间的功能连接减弱提示核心子系统对背内侧前额叶的约束力下降(Christoff et al., 2016)，个体消耗更多的认知资源进行消极的自我审视。核心子系统与内侧颞叶子系统的连接增强提示前者对后者存在过度约束，使个体难以提取积极的自传体记忆，因而无法基于以往记忆形成适应性的心理活动。此外，基于图论分析的脑网络研究表明，无论是健康受试者还是抑郁症患者，反刍思维量表得分越高的人，默认网络内部熵水平更高 (Jacob et al., 2020)。熵反映了一个系统的秩序，熵水平增高表示系统秩序趋于混乱 (Jacob et al., 2016)。因此，该研究结果表明，反刍思维水平能够被刻画为默认网络内部的有序程度。

默认网络在支持个体内部指向的心理活动中起着非常重要的适应性作用，而反刍思维与默认网络的异常活动有关，从中不难理解为何反刍思维会表现出过度的自我参照加工。但是反刍思维与默认网络异常活动之间的因果关系尚不明确，未来研究应该更多地利用有向功能连接或者神经调控方法来明确二者之间的作用方式。

3 反刍思维的消极情绪性

Nolen-Hoeksema(1987)认为反刍思维是个体在面对抑郁情绪时所采取的反应方式。在

遭遇了消极的生活事件之后，反刍思维水平高的个体更加关注该事件中自身的消极情绪，对事件中的细节和自身情绪状态进行过度加工。而由消极情绪引发的认知偏差，不利于个体客观地解决问题(Nolen-Hoeksema et al., 2008)。研究表明，突显网络的改变可以解释反刍思维状态下消极情绪的产生。

突显网络(salience network, SN)有两个关键作用，一是对外部环境进行检测，二是基于此获取相应的认知资源。突显网络主要包含杏仁核(amygdala)、额-岛叶(fronto-insular cortex)、前扣带回(anterior cingulate cortex) (Lydon et al., 2019; Peters et al., 2016)。基于Stroop任务(Wagner et al., 2013)的研究发现，相较于健康控制组，抑郁症患者表现出更多的负性自我参照加工，这提示了抑郁症与反刍思维高度相关；并且在任务过程中，由突显网络的关键节点前扣带回与默认网络的内侧前额叶所构成的前皮质中线结构(anterior cortical midline)表现出过度激活和功能连接增强。而Nejad等人(2013)在对抑郁症患者的反刍思维脑网络研究进行系统梳理后发现，前皮质中线结构的过度激活使背外侧前额叶与杏仁核之间的功能连接降低。由于背外侧前额叶负责认知控制(Nejati et al., 2021)，而杏仁核与情绪加工有关(Bordi & LeDoux., 1992)，反刍思维下两者之间的功能连接降低提示个体难以合理编码及准确表征信息，也难以形成建设性的情绪管理策略，从而产生消极的情绪反应。这一点得到了图论分析结果的支持。节点中心度(centrality)是图论分析中常用的一项指标，能够刻画节点在网络中的作用和地位，其值越高表明该节点在网络中的信息传输作用越大(梁夏等, 2010; 孙俊峰等, 2010; Gao et al., 2018)。研究发现，通过情绪指令诱发受试者的反刍状态之后，相较于健康控制组，高反刍特质的抑郁症患者在任务过程中表现出杏仁核节点中心度的降低(Zhang et al., 2020)。这表明当抑郁症患者进入反刍思维状态之后，杏仁核无法充分发挥情绪管理的作用，情绪状态得不到合理的调整。

突显网络中的额-岛叶参与感知觉和情绪加工(Li et al., 2018)。研究表明右额-岛叶的静息态功能连接增强与消极、持续性的内省倾向有关(Kaiser et al., 2016)，反映了抑郁症患者的反刍思维水平。此外，高反刍特质(反刍思维量表得分高)者存在对消极自我描述信息的注意偏向，并且这种注意偏向受到了额-岛叶动态功能连接的调节，具体表现为额-岛叶动态功能连接变化越大，高反刍特质者越倾向于注意消极的自我信息(Kaiser et al., 2018; Kaiser et al., 2019)。额-岛叶的神经活动体现了个体主观预期与现实情境产生冲突时本体状态(somatic states)的差异(Craig, 2009; Sridharan et al., 2008)，因此，额-岛叶的过度活跃表明，当现实情景达不到个体的主观预期时，高反刍特质者更容易产生强烈的消极情绪体验。而对于目标的追求是十分主观的，失败的目标与预期目标落差越大，产生消极反刍思维的可能性就越大。

总之，负责对内外环境进行监测的突显网络在反刍思维状态下发生了改变，个体将注意力聚焦于消极的情绪体验，既无益于身心健康也无益于问题解决。消极情绪性也是反刍思维与抑郁症、焦虑症等精神疾病有关的原因之一。上述分析提示，对反刍思维的干预可

以采用培养高反刍特质者对自身相关消极情绪的钝感以减少其过度精神内耗的思路。

4 反刍思维的持续性

反刍思维是一种非适应性的认知风格，表现为个体对消极事件进行重复持续的思考(Grafton et al., 2016; Nolen-Hoeksema et al., 2008)。何以反刍思维一旦开始便难以停止？注意脱离损伤假说(impaired attention disengagement theory)提出，个体难以从消极刺激中转移注意力而产生了反刍思维，由此促使个体对自我相关的消极信息进行重复持续的加工(Grafton et al., 2016; Hur et al., 2019; Koster, 2011; Nejad et al., 2019; Valenas et al., 2017)。研究表明，反刍思维的持续性与注意相关网络之间的功能连接异常有关。

由背外侧前额叶和后顶叶皮层构成的额顶网络(frontoparietal network, FPN)主要参与注意控制、反应选择和反应抑制(Chang, Liu, et al., 2013; Lydon et al., 2019)。由额眼区和顶内沟构成的背侧注意网络(dorsal attention network, DAN)则有助于集中和维持对外部刺激的注意，其激活度与反刍思维呈负相关(Buckner & Krienen, 2013; Rosenbaum, Thomas, et al., 2018; Rosenbaum, Maier, et al., 2018)。研究表明，相较于健康控制组，抑郁症患者的高反刍思维水平体现于额顶网络与背侧注意网络之间的功能连接减弱、以及额顶网络与默认网络之间的功能连接增强(Kaiser, Andrews-Hanna, Wager, et al., 2015; Kaiser, 2017)。具体而言，额顶网络不仅参与自上而下的注意和情绪调节，也负责对背侧注意网络、默认网络进行认知资源分配与管理。当额顶网络与外部指向的背侧注意网络之间的功能连接减弱、与内部指向的默认网络之间的功能连接增强时，本应用于关注外部世界及获取外部信息所需的认知资源被内部指向的心理活动所占用。过多的认知资源进入到自我参照和自传体记忆的加工系统，个体的注意力过多投入于对自我的关注。

动态脑网络研究也为反刍思维的注意脱离损伤假说提供了证据。动态脑网络分析能够描述功能连接随时间变化的稳定性(stability)，也能反映脑网络的灵活程度(即，功能连接越稳定，脑网络的灵活性越差)(Gonzalez-Castillo & Bandettini, 2018; Li, Lu et al., 2020)。研究发现，相较于分心控制组(想象非情绪性的场景)，反刍思维组在进行自我反思时其额顶网络的功能连接稳定性增高，而默认网络的稳定性降低(Chen & Yan, 2021)。这提示，在反刍状态下，个体的思维模式僵化，自我参照加工异常突出(Christoff et al., 2016; Kaiser et al., 2016)。Chen 和 Yan(2021)认为，默认网络稳定性的降低与其内部脑区之间过于密集的互动有关。但这一点需要在未来研究中加以验证。总体而言，额顶网络与默认网络动态活动模式的异常可能反映了反刍状态下个体难以将注意力从与自我相关的信息中脱离出来。

然而关于反刍思维持续性的成因，也有学者提出了不同的看法。Yang 等人(2017)通过元分析发现，高反刍思维者的认知控制能力下降，以致于在抑制消极信息上出现困难。但是关于抑制能力与反刍思维持续性之间关系的脑网络分析较少，尚无法明确其脑网络机制反刍思维的持续性是由于个体难以从消极的自我信息中转移注意，还是由于个体难以抑制

消极刺激，需要未来研究做出回答。

5 总结与展望

总体而言，反刍思维是个体在经历过消极事件后所采用的非适应性反应方式，具有负性自我参照加工、消极情绪性以及持续性的特点。反刍思维的负性自我参照加工可以从默认网络的核心子系统、背内侧前额叶子系统、内侧颞叶子系统的异常活动模式中得到解释而其所产生的消极情绪，则与突显网络中前扣带回、杏仁核的异常功能连接有关；额-岛叶频繁的动态功能连接变化体现了现实情境与预期目标之间的冲突容易使高反刍思维者产生强烈的消极情绪体验。最后，之所以个体难以主动停止持续不断的反刍思维，与额顶网络背侧注意网络、默认网络之间异常的耦合模式有关。虽然目前关于反刍思维脑网络机制的研究已经取得了一定的进展，但未来仍需要从以下几方面加深对其的认识。

首先，以往绝大多数研究所呈现的是反刍思维与脑网络活动之间的相关性，但相关关系不足以明确二者之间孰因孰果。对此，未来可以运用神经调控技术考察反刍思维与脑功能连接改变之间的因果关系，以加深对反刍思维脑网络机制的认识。

第二，反刍思维的脑功能网络的改变是否存在结构基础。现有研究已经证实反刍思维存在着显著的脑功能网络改变基础，但仅凭功能连接的变化不足以推测是否存在结构连接的改变(Koch et al., 2002)。目前，少有研究就反刍思维的脑功能与结构网络之间的关系进行针对性的探索，未来应从这一方向加深对反刍思维脑机制的理解。

第三，反刍思维的老龄化特征。以往参与反刍思维研究的受试者以青中年群体为主，然而，大脑随着年龄增长而不断改变(Gu et al., 2015)，因此简单地将这些研究结果推广到老年人群并不合适。研究表明，相较于年轻人，老年人在面对消极情绪的时候会更倾向于使用分心策略而较少陷入反刍状态(Ricarte Trives et al., 2016)。这或许是因为老年人群体中存在着积极效应，即老年人相对于年轻人会更加关注积极刺激而非消极刺激(Reed et al., 2014)。反刍思维所体现出来的脑网络异常连接是否会随着情绪积极效应而得到改善，需要在未来的研究中加以验证。

最后，大尺度脑网络的临床价值。反刍思维对抑郁症、焦虑症等多种精神疾病所产生的影响日益受到重视。目前少有研究将现有脑网络机制的成果应用于反刍思维的临床干预与治疗。未来研究应致力于发展基于脑网络的神经调控技术，以对反刍思维施以有效的干预。

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Functional brain networks underlying rumination

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Abstract: Rumination refers to the repeated reflection of cause, course, and consequence of a negative event. Brain network studies based on functional magnetic resonance imaging indicate that the self-referential processing involved in rumination is associated with alterations in the default mode network, while negative emotion produced by rumination is related to changes in the salience network. The "persistence" property of rumination is associated with altered connections between attention-related networks. Future studies should further examine the causal relationship between rumination and its related brain networks and explore the structural basis of functional networks of rumination to deepen our knowledge about the brain basis of rumination. It is not only in great need to investigate the aging effect on rumination and its underlying brain networks, but also to develop neuromodulation techniques for intervention.

Keyword: rumination, brain network, default mode network, functional connectivity